FINAL

BASELINE HUMAN HEALTH RISK ASSESSMENT FOR THE VASQUEZ BOULEVARD AND INTERSTATE 70 SITE, OPERABLE UNIT 2 DENVER, COLORADO

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LIST OF ACRONYMS AND ABBREVIATIONS

ABA	Absolute Bioavailability
AF	Absorption Fraction
AT	Averaging Time
ATSDR	Agency for Toxic Substances and Disease Registry
BKSF	Biokinetic Slope Factor
BW	Body Weight
CDPHE	Colorado Department of Public Health and Environment
CDC	Center for Disease Control
CDOT	Colorado Department of Transportation
COPC	Chemical of Potential Concern
CTE	Central Tendency Exposure
DI	Daily Intake
ED	Exposure Duration
EF	Exposure Frequency
EPC	Exposure Point Concentration
GM	Geometric Mean
GSD	Geometric Standard Deviation
HEAST	Health Effects Assessment Summary Tables
HI	Hazard Index
HIF	Human Intake Factor
HQ	Hazard Quotient
IEUBK	Integrated Exposure Uptake Biokinetic
IR	Intake Rate
IRIS	Integrated Risk Information System
LOAEL	Lowest-Observed-Adverse-Effect-Level
LOEC	Lowest-Observed-Effect-Concentration
MRL	Minimum Risk Level
NCEA	National Center for Environmental Assessment
NHANES	National Health and Nutrition Evaluation Survey
NOAEL	No-Observed-Adverse-Effect-Level
OERR	Office of Emergency and Remedial Response
ORNL	Oak Ridge National Laboratory
OU	Operable Unit
P10	Probability of having a blood lead concentration that exceeds 10 µg/dL
PbB	Concentration of lead (Pb) in Blood
PbS	Concentration of lead (Pb) in Soil
PPRTV	Provisional Peer Reviewed Toxicity Values
RAGS	Risk Assessment Guidance for Superfund
RBA	Relative Bioavailability

RBC	Risk Based Concentration
RfC	Reference Concentration
RfD	Reference Dose
RME	Reasonable Maximum Exposure
SF	Slope Factor
TAL	Total Analyte List
TWA	Time Weighted Average
UCL	Upper Confidence Limit
USEPA	United States Environmental Protection Agency
VBI70	Vasquez Boulevard and Interstate 70
WOE	Weight of Evidence

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1.0 INTRODUCTION

1.1 Purpose of this Document

This document is a baseline human health risk assessment for Operable Unit 2 of the Vasquez Boulevard and Interstate 70 (VBI70) Site in Denver, Colorado. Operable Unit 2 focuses on the area of the site formerly occupied by the Omaha & Grant Smelter. The purpose of the document is to assess the potential risks to human receptors, both now and in the future, from site-related contaminants present in environmental media, assuming that no steps are taken to remediate the environment or to reduce human contact with contaminated environmental media.

The results of this assessment are intended to help inform risk managers and the public about potential human risks attributable to site-related contaminants and to help determine if there is a need for action at the site (USEPA 1989). The overall management goal is to ensure protection from deleterious effects of acute and chronic exposures to site-related chemicals for both current and future land uses.

The methods used to evaluate risks in this assessment are consistent with current USEPA guidelines for human health (USEPA 1989; 1991a; 1991b; 1992a; 1993; 2002a; 2002b) provided by the USEPA for use at Superfund sites.

1.2 Organization of this Document

In addition to this introduction, this report is organized into the following sections:

Section 2	This section provides a description of the site and a review of data that characterize the nature and extent of environmental contamination at the site.
Section 3	This section identifies human exposure scenarios of potential concern at the site, identifies chemicals of potential concern (COPCs) for each exposure scenario, and derives quantitative estimates of exposure for those pathways that are most likely to be significant.
Section 4	This section summarizes the characteristic cancer and non-cancer health effects to humans associated with the COPCs at the site and lists the quantitative toxicity factors used to calculate cancer and non-cancer risk levels in exposed humans.
Section 5	This section provides quantitative estimates of cancer and non-cancer risk to humans exposed to site-related contaminants by each of the exposure scenarios of primary concern.

Section 6	This section summarizes the likely magnitude and direction of the sources of uncertainty in the risk estimates for human receptors.
Section 7	This section provides full citations for USEPA guidance documents, site-related documents, and scientific publications referenced in the baseline risk assessment.

2.0 SITE CHARACTERIZATION

2.1 Site Description

The Vasquez Boulevard/Interstate 70 (VBI70) Superfund Site is located in the north-central portion of Denver, Colorado, near the intersection of Interstate 70 and Vasquez Boulevard. Three major smelters have operated in the vicinity of the VBI70 site, including the Argo Smelter, the Omaha and Grant Smelter, and the ASARCO Globe Smelter (Figure 2-1). The VBI70 site consists of three Operable Units (OUs):

- Operable Unit 1 (OU1) - Off-facility (non-smelter) soils (residential soils)
- Operable Unit 2 (OU2) - Omaha and Grant Smelter on-facility soils
- Operable Unit 3 (OU3) - Argo Smelter on-facility soils

This document is an assessment of the potential for exposure and risk to human receptors due to releases from the former Omaha and Grant Smelter site, designated as Operable Unit 2 (OU2) of the VBI70 Superfund Site.

2.1.1 Location

The VBI70 OU2 site is located on 67 acres of land within the City and County of Denver, Colorado, at approximately the intersection of 42nd Avenue and Vincent Street. Figure 2-2 shows the property previously occupied by the Omaha and Grant Smelter which is bounded by:

- Northwest – Colorado and Eastern Railroad (Burlington Northern Santa Fe railroad)
- Northeast – Union Pacific Railroad
- Southwest – 39th Avenue
- Southeast – Brighton Boulevard (formerly Wewatta Street)

2.1.2 Land Use

Land Use at the VBI70 OU2 Site

The historical land use at the VBI70 OU2 site was primarily industrial and included smelting (1883 – 1903) and municipal waste incineration (1933-1945) (EnviroGroup 2001). The locations of the historical smelter facilities are presented in Figure 2-3.

The current land use at the VBI70 OU2 site is primarily commercial/industrial, with recreational use at a small portion of the site located in the western corner immediately adjacent to the South Platte River at the Globeville Landing Park (Figure 2-3). The ground is largely covered by highways, building structures, and paved parking lots. Grassy or unpaved areas are rare and are mainly restricted to the western most portion of the site at the Globeville Landing Park and some small areas at some of the commercial properties along Brighton Boulevard and 39th Avenue on the eastern and southern portions of the site.

The potential future land use of the VBI70 OU2 site is multi-family residential, with the approximate size of the multi-family units ranging from 5 to 20 acres (EMS Inc., 2008).

In this risk assessment, the area located within the National Priorities List (NPL) site boundary (see Figure 2-2) is considered "on-site".

Surrounding Land Use

The land use surrounding the VBI70 OU2 site is mainly commercial/industrial, interspersed with private residences, and with recreational land use along the South Platte River (EnviroGroup, 2001; CDPHE 1992).

In this risk assessment, the area located outside of the NPL site boundary (see Figure 2-2) is considered "off-site".

2.1.3 Topography

The VBI70 OU2 Site is located on the east bank of the South Platte River. The topography of the site varies from approximately 5195 feet above mean sea level along the eastern boundary of the site to approximately 5137 feet along the South Platte River. The general drainage pattern is from the southeast toward the northwest toward the South Platte River. The South Platte River floodplain in the vicinity of the site is approximately 300 feet wide and approximately 9 feet lower than ground elevations along the east bank of the river (EnviroGroup, 2001).

The site topography has been altered by fills and excavations over the 100-years of activity at the site. All smelter features, such as slag piles and buildings have been removed although buried building debris and facility foundations may still exist at VBI70 OU2 below modern day facilities and paved areas (EnviroGroup, 2001).

2.1.4 Geology and Hydrogeology

Detailed information on the geology and hydrogeology in the area of the site is described in Robson and Romero (1981), Robson (1996), the preliminary assessment for the site (CDPHE, 1992), and in the Draft Facility Conceptual Model for the site (EnviroGroup, 2001). Information from these sources that is helpful in performing an evaluation of potential human health and ecological risks at the site is summarized below.

Geology

The VBI70 OU2 site is located east of the Front Range of the southern Rocky Mountains. The sedimentary rocks underlying the region are known as the Denver Basin, an asymmetric, north-south trending structural basin. The uppermost bedrock formation below the site is the Denver Formation, consisting of inter-bedded claystone and shale (typically about 70%), and siltstone with silty sandstone lenses (typically about 30%) (CDPHE, 1992). The approximate depth to the eroded bedrock surface in the vicinity of the VBI70 OU2 site ranges from 35 feet to 45 feet below ground surface (EnviroGroup, 2001).

Unconsolidated sediments, comprised of alluvium, colluvium, and eolian deposits overlie most of the bedrock in the Denver area. The thickness of the unconsolidated sediments is generally less than 20 feet. However, there are some areas within the Denver Basin where the thickness of unconsolidated sediments exceeds 80-100 feet (Robson, 1996). Broadway Alluvium and younger Post-Piney Creek Alluvium and artificial fill (including smelter slag) overlie the claystone at the VBI70 OU2 site.

Hydrogeology

There are two primary groundwater systems underlying the site: an upper shallow alluvial system and a deeper bedrock aquifer (the Denver Aquifer). The two systems are separated by more than 70 feet of low permeability claystone. The depth to groundwater in the shallow alluvial system usually ranges from about 10-20 feet below the ground surface. The shallow alluvial system is comprised of sand and gravel that contains various amounts of clay and silt. In some areas these coarse grained materials grade to a fine material, with clay and silty materials predominating. Due to the higher hydraulic conductivity of the weathered bedrock than the underlying unweathered bedrock, groundwater preferentially flows horizontally in the alluvial/weathered unit rather than downward towards the deep bedrock aquifer (CDPHE, 1992). Regionally, the direction of groundwater flow in the upper alluvial system is to the northwest toward the South Platte River (EnviroGroup 2001).

2.1.5 Basis for Concern

Smelter operations are often associated with the generation and release of various types of metal-containing waste materials, including slag. Environmental media which may be impacted by environmental releases include surface soil, subsurface soil, and groundwater. Most metals in smelter wastes can cause adverse effects in humans if contamination and exposure levels are high enough.

The potential sources of chief concern at the former Omaha & Grant Smelter are historic smelting-related solid wastes, potentially including slag, stack emissions, and other solid and liquid wastes generated and disposed of on the site. Such wastes and contamination may exist both in current surface soils (that which exists immediately below current paved areas at the site) as well as in buried subsurface deposits. Contaminants leaching from surface and subsurface sources may also migrate into the groundwater (CDPHE 1992).

2.2 Site Investigations

Several investigations have collected samples of soil, groundwater, surface water and/or sediment at or in the vicinity of the VBI70 OU2 site. The available data for soil, surface water and sediment are briefly described below and are summarized in Table 2-1 and Table 2-2. Because exposure to groundwater is not evaluated in this risk assessment (see Section 3.2.1), these data are not described in detail below, but instead are provided in the QAPP/SAP (EMS, Inc., 2008).

2.2.1 Soil Data

VBI70 OU2 Remedial Investigation

2004 - 2005

Both surface and sub-surface soil samples were collected at the site in support of the remedial investigation at VBI70 OU2. A total of 25 surface soil samples (0-2") were collected from areas of currently exposed soil at the site. A total of 41 subsurface soil samples were collected from 10 borings (7 soil borings and 3 monitoring well borings) located in areas of the site that were most likely to have been impacted by historic operations, releases, and on-site disposal (EnviroGroup 2004). Grab samples were collected from the top 6-8" of each sub-surface soil horizon at depths up to 20 feet below ground surface. Both surface and sub-surface soil samples were analyzed for total arsenic, cadmium, lead and zinc. These four analytes were retained for analysis based on the results of previous investigations at the other two operable units at VBI70 and based on the results of previous investigations at the nearby Globe Plant site. Sample locations are shown in Figure 2-4 (see "BH Soil Samples", "MW Holes", "XXXX Brighton Blvd" and "4600 Humbolt Blvd" sample locations) (EnviroGroup 2004).

2008

In December 2008, CCOD collected additional surface soil and subsurface soil samples from the VBI70 OU2 site in support of the remedial investigation/feasibility study and risk assessment at the site. A total of 14 surface soil samples and 33 subsurface soil samples were collected from 14 stations, shown in Figure 2-4 (see "2008 Drilling" locations). Samples were analyzed for total lead and arsenic. These two chemicals were identified as the chemicals of potential concern at the site, based on a review of the historical soil samples collected at the site and the draft risk assessment report (USEPA 2006) that was prepared for the VBI70 OU2 site (EMS Inc. 2008).

Surface soil samples were collected from the top one foot of soil (0-1 foot). In cases where the soil was bare, the sample depth is 0-1 foot below ground surface (0-1 foot bgs). In cases where the soil was covered by pavement, it is anticipated that the thickness of pavement and base course is approximately 1 foot, so the top foot of soil is anticipated to occur at a depth of 1-2 feet bgs or 0-1 foot below pavement surface (0-1 foot bps). The entire one foot sample was homogenized and submitted for analysis for lead and arsenic by ICP-MS (method 6020B).

Subsurface samples consisted of composite samples collected over 5 foot depth intervals (e.g., 0-4 feet, 4-9 feet, and 9-14 feet). Sub-samples were collected from each 1 foot portion of the 5 foot core and were combined, homogenized and submitted for analysis lead and arsenic by ICP-MS (method 6020B).

Brighton Boulevard Phase II Targeted Brownfield Site Assessment

During April-May of 2003 and January of 2004, sub-surface soil samples were collected at and adjacent to the VBI70 OU2 site as part of the Phase II Environmental Site Assessment of the Brighton Boulevard brownfield site (URS 2004). As part of this investigation, a total of 6 sub-surface soil samples were collected from the southeast edge of the VBI70 OU2 site, along Brighton Boulevard. Borings were advanced until groundwater or refusal. Composite samples were collected over the top coring interval (0-3 feet or 0-4 feet bgs) and analyzed for the 23 Target Analyte List (TAL) metals. Sample Locations that are considered on-site for the VBI70 OU2 risk assessment are shown in Figure 2-4 (see "BB-BB-XX" samples).

City and County of Denver Coliseum Barn Soil Excavations

In October 2003, surface soil and sub-surface soil samples were collected at the VBI70 OU2 site during excavation activity at the Coliseum Barn (located on the west side of the Coliseum proper) to support the structural reinforcement of the barn roof (CH2MHill 2004). A total of 2 surface soil samples and 5 sub-surface soil samples were collected. Surface soil samples were composite from soil surrounding the excavation areas. Four sub-surface samples were collected from excavations at the four corners of the barn structure. Samples were composite over a depth of 0-5 feet below ground surface. Additionally, 1 sub-surface grab sample was collected from one excavation that appeared to be the most contaminated. Soil samples were analyzed for RCRA metals using EPA Method 6020A. Sample Locations are shown in Figure 3-4 (see "Barn Samples").

Globeville Landing Park Soil Sampling

In July of 2002, sub-surface soil samples were collected from the Globeville Landing Park to characterize arsenic and lead concentrations in soil for workers who may be exposed during maintenance activities (CH2MHill, 2002). A total of 64 sub-surface soil samples were collected from 32 locations at depths of 0-2 and 2-3 feet below ground surface. At 3 locations, additional subsurface samples were collected at depths of 4-6 feet below ground surface. Composite samples were collected over the sampling depth interval and analyzed for arsenic and lead. Sample locations are presented in Figure 2-4 (see "SB Soil Samples").

Pepsi Bottling Group Soil Testing for Lead and Arsenic

During the period of August 2001 through January 2002, Pepsi Bottling Group collected samples of soils disturbed during construction activities at 7 areas of its facility located at the VBI70 OU2 site (Transportation Industrial Services Inc., 2001a through 2002). During these investigations, 10 sub-surface soil samples were collected from 5 on-site locations. Sub-surface samples were composite over 2 depths (0-10 and 10-20 feet below ground surface) at each sample location and analyzed for lead and arsenic. Most of these sample locations are shown in Figure 2-4 (see "Pepsi Area X Soil Samples" and "Pepsi UT (Utility Trenches) Soil Locations").

Colorado Department of Transportation

As part of planning modifications to Interstate 70 (I-70), the Colorado Department of Transportation (CDOT) conducted site investigations (Walsh 1991 and 1997) along I-70, at and in the vicinity of the northern boundary of the VBI70 OU2 site. During these investigations, a total of 6 sub-surface soil samples were collected at 6 on-site locations. Sub-surface soil samples were composite over the borehole depth, which ranged from 11.5 to 22 feet below ground surface. Samples were analyzed for 16 metals (As, Ba, Be, Cd, Cr, Co, Cu, Fe, Pb, Mn, Hg, Ni, Se, Ag, V, Zn). Sample locations are presented in Figure 2-4 (see "CDOT Holes).

2.2.2 Surface Water and Sediment Data

VBI70 OU2 Remedial Investigation

Data collection for the Remedial Investigation (EnviroGroup 2004) also included the collection of paired surface water and sediment data from 2 locations in the South Platte River shown in Figure 2-5. The stations sampled were positioned upgradient (station N43) and downgradient (station N46) of the site to evaluate any impacts to the South Platte River from groundwater discharging from the site. Surface water samples were analyzed for total and dissolved metals (As, Cd, Cu, Pb, Zn) and sediment samples were analyzed for total metals (As, Cd, Cu, Pb, Zn). Additional surface water samples were collected monthly from the downgradient station (N46) for part of 2005 (EnviroGroup 2004).

2.3 Data Evaluation

2.3.1 Data Usability for Risk Assessment

Soil

Although complete laboratory data packages for soil samples were not available for review, because the data were collected in accordance with documented plans and/or procedures and for the most part using EPA-approved analytical methods, all soil data were determined to be acceptable for use in the RI and risk assessment (EMS Inc., 2008).

Surface Water and Sediment

The surface water and sediment data were also reviewed to determine their suitability for use in risk assessment. Because the surface water and sediment data were collected in accordance with documented plans and/or procedures approved by EPA, all soil data were determined to be acceptable for use in the risk assessment.

2.3.2 Summary Statistics

All data used in the risk assessment are provided electronically in Appendix A.

Summary statistics for the concentrations of metals in site media are presented in Tables 2-3 through 2-4.

In site soil, several metals, including those typically associated with mining-related activities (arsenic, cadmium, copper, lead and zinc), were frequently detected. Arsenic and lead were present at very high levels in some sub-surface samples, with maximum concentrations of 950 mg/kg and 3,600 mg/kg, respectively.

In surface water and sediment, metals were frequently detected in samples collected from both upgradient and downgradient stations. Concentrations in surface water and sediment in upgradient stations were generally similar to those observed at downgradient stations, with one exception. Concentrations of lead in sediment tended to be higher at the upgradient station than those observed in samples collected from the downgradient station.

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3.0 EXPOSURE ASSESSMENT

Exposure is the process by which human receptors come into contact with chemicals in the environment. In general, receptors can be exposed to chemicals in a variety of environmental media (e.g., soil, water, air, food), and these exposures can occur through several pathways (e.g., ingestion, dermal contact, inhalation). Section 3.1 identifies human receptors that may be exposed to site-related contaminants and the exposure pathways that might result in these receptors coming into contact with site-related contaminants. Section 3.2 provides an evaluation of exposure pathways that could lead to contact with site-related contaminants at this site and identifies the pathways that are believed to be the most significant at the site. Section 3.3 identifies chemicals of potential concern. Section 3.4 describes the methods used to quantify exposure from each pathway that is considered to be of possible significance, describes the selection of exposure points, and describes the calculation of exposure concentrations for human receptors.

3.1 SITE CONCEPTUAL MODEL

Figures 3-1 presents the site conceptual model showing how chemicals that may have been released from the former Omaha & Grant Smelter might result in exposure of human receptors.

3.1.1 Exposed Populations

As seen in Figure 3-1, based on the current and expected future land use, the human populations most likely to be exposed to site-related contaminants now and in the future are commercial workers, construction workers, recreational visitors and future residents. Each of these populations is briefly described below.

Commercial Workers

The commercial worker population represents individuals who visit the site during a regular work day at a hypothetical future on-site commercial business. This type of worker is assumed to work primarily indoors, but may occasionally work outdoors where direct contact with exposed surface soil may occur.

Construction Workers

The construction worker population represents individuals who may visit the site for a short period of time (e.g., 8 hours/day, for one year or less) and are involved in excavation activities such as the installation or repair of utility lines, building foundations, expanding or repairing the highway, etc., where intensive contact with surface and subsurface soil may occur.

Recreational Visitors

The recreational visitor population represents older children/adolescents (7-15 years of age) who may visit the Globeville Landing Park area of the site to engage in recreational activities such as picnicking, walking or biking, over an extended period of time. Exposures might occur to soil in the park, or to surface water and sediment along the bank of the South Platte River.

Hypothetical Future Residents

The hypothetical future resident population represents individuals that could live on the site in the future, if the site were ever redeveloped from commercial/industrial use to residential land use. Future residents may have direct contact with surface soil in their yards over a long period of time (around 30 years).

3.2 RELATIVE IMPORTANCE OF EXPOSURE PATHWAYS

As noted above, humans could be exposed to site-related contaminants by several pathways. However, not all of these exposure routes are likely to be of equal concern. Exposure scenarios that are considered to be potentially significant are shown in Figure 3-1 by boxes containing a solid black circle. Pathways that are judged to contribute only occasional or minor exposures are shown by boxes with an "X". Incomplete pathways (i.e., those which are not thought to occur) are shown by open boxes. The following sections provide the basis for identifying the relative significance of these pathways.

3.2.1 Human Exposure Pathways

On-Site Commercial Workers, Construction Workers, and Future Residents

Incidental Ingestion of Soil and Soil-Like Media

Even though few people intentionally ingest soil, commercial workers, construction workers, and residents who have direct contact with soil at the site might ingest small amounts that adhere to their hands during outdoor activities. In addition, soil can enter buildings (such as workplaces or residences) leading to contamination of indoor dust, which may also be ingested by hand to mouth activities. Although exposure of commercial workers to surface soil is largely prevented by the high degree of building and pavement cover at the site, future land owners at the site could potentially remove existing buildings or pavement and expose the underlying surface soils. Construction workers could be exposed now or in the future as a consequence of excavation activities such as installation or repair of utility lines, building foundations, etc. If in the future, the site were redeveloped for residential use, hypothetical future residents could be exposed to surface soil at the site. Incidental ingestion of soil is often one of the most important routes of human exposure at a site, so ingestion of soil and other soil-like media by current or future commercial workers and construction workers, and by future residents is evaluated quantitatively in the risk assessment.

Dermal Contact with Soil

Construction workers and, to a lesser extent, commercial workers and future residents, may get soil on their skin while working or playing outdoors in activities involving direct contact with soil. Even though information is limited on the rate and extent of dermal absorption of metals in soil across the skin, most scientists consider that this pathway is likely to be minor in comparison to the amount of exposure that occurs by soil and dust ingestion. This view is based on the following concepts: 1) most people do not have extensive and frequent direct contact with soil, 2) most metals tend to bind to soils, reducing the likelihood that they would dissociate from the soil and cross the skin, and 3) ionic species such as metals have a relatively low tendency to cross the skin even when contact does occur. Based on this, and recognizing that current methods and data are very limited for attempting to quantify dermal absorption of chemicals from soil, dermal contact with soil is not evaluated quantitatively in this risk assessment.

Inhalation of Airborne Soil Particulates

Whenever contaminated soil is exposed at the surface, particles of contaminated surface soil may become suspended in air by wind or mechanical disturbance, and humans in the area could inhale those particles. However, this exposure pathway is usually very small compared to oral exposure (see Appendix B), and therefore this pathway is evaluated qualitatively rather than quantitatively.

Exposure to Groundwater

At present, groundwater at the site is not used as a source of drinking water, nor is it likely to be used as a source of drinking water in the future. Thus, ingestion of and dermal contact with groundwater pathways are not evaluated quantitatively in this assessment.

On-Site Recreational Visitors

Exposure to Soil

Recreational visitors that picnic, walk or bike at the Globeville Landing Park might have direct contact with surface soil leading to potential ingestion or dermal exposure. However, the soils in the Park area are mainly clean fill that was brought in from other areas during park construction, so evaluation of this pathway is not needed in the risk assessment (USEPA 2003c).

Ingestion of Surface Water and Sediment

Older children or adolescents (7-15 years of age) who visit the Globeville Landing Park area of the site may engage in activities such as wading and splashing. Although it is not expected that they intentionally drink water or ingest sediment from the river, these activities can lead to incidental ingestion of surface water and/or sediment, so these pathways were selected for quantitative evaluation. As noted above, methods for quantification of dermal exposure to water and soil (or soil like material) are limited, so these pathways were not evaluated quantitatively in this risk assessment.

Ingestion of Fish

Older children or adolescents who visit the Globeville Landing Park may also catch fish from the South Platte River, and could ingest site-related contaminants in fish tissue. While conceptually, this is a potentially complete exposure pathway, this activity is not likely to occur very often at the site. Furthermore, most inorganic chemicals (metals) do not readily accumulate in fish tissue. Based on this, ingestion of contaminants in fish tissue is judged to be a minor exposure pathway, and is not evaluated quantitatively by the risk assessment.

Off-Site Commercial Workers, Construction Workers, and Residents

Incidental Ingestion of Soil

Historical smelter emissions and wind transport of particles from on-site soils may have deposited contaminants in soils at off-site locations near the former smelter. Off-site residents, commercial workers, and/or construction workers may ingest contaminated surface soil both during outdoor activities that bring them into direct contact with the soil, and also by ingestion of indoor dust that has become contaminated with outdoor soil. Although some areas near the site are largely covered with buildings or pavement, some areas of exposed surface soil do exist.

The remedial investigation for the VBI70 OU1 site evaluated the concentrations of smelter-related contaminants in residential surface soils in the vicinity of the former Omaha & Grant Smelter (USEPA 2001a, WGI 2001). These data are considered "off-site" surface soils for the VBI70 OU2 site. Areas of potential concern to current or future residents that were identified by this investigation have been or will be remediated. On this basis, further evaluation of off-site residential exposure to soil is not quantified in this risk assessment.

Commercial properties were not specifically evaluated during the VBI70 OU1 investigation, and thus there could be off-site locations where lead and arsenic in surface soil might be of potential concern to commercial or construction workers. In order to determine if risks might be of potential concern to off-site workers, risk-based concentrations were calculated for lead and arsenic (see Table 3-1 and Appendix C) and compared to the maximum concentrations of lead and arsenic measured in off-site surface soils that were measured at residential properties at the VBI70 OU1 site. This assumes that the distribution of lead and arsenic in surface soil at off-site residential properties is generally similar to the distribution of lead and arsenic in surface soil at off-site commercial properties. Table 3-1 presents the results of this evaluation. As seen, there were no locations that are of potential concern for either a commercial worker or a construction worker to lead. For arsenic, 3 out of 2,969 off-site locations would be of potential concern for a commercial worker and 6 out of 2,969 off-site locations would be of potential concern for a construction worker. Figure 3-2 shows the location of these 6 properties. As shown, all of these properties are located east/southeast of the site, and none are located in areas that are predominantly downwind (either south or northeast) of the former smelter. Consequently it is considered unlikely that the exceedences are attributable to wind-borne transport of smelter emissions or site soils, indicating the contamination is not likely to be smelter-related.. Based on this, while exposure to off-site surface soils may be a complete pathway for current and future commercial and for future construction workers, it is not likely that site-related releases contribute to a potentially significant exposure pathway, and thus is not evaluated quantitatively in this risk assessment.

Dermal Contact with Soil

As noted above, dermal contact with metals in soil is not evaluated quantitatively because methods for quantification of this pathway are limited and because the pathway is suspected to be minor compared to oral exposure.

Inhalation of Airborne Dust

As noted above, inhalation exposure to metals in airborne dust is usually small compared to oral exposure (see Appendix B). Therefore, this pathway is evaluated qualitatively for off-site residents and workers.

Exposure to Groundwater

Exposure of off-site residents or workers to groundwater is not currently a complete exposure pathway, as groundwater flows from the site to the South Platte River. It is extremely unlikely that the groundwater will be used as a drinking water source in the future, thus hypothetical future use of groundwater by off-site residents and off-site commercial workers is not evaluated quantitatively in this risk assessment.

3.2.2 Summary of Pathways of Principal Concern

Based on the evaluations above, the following pathways are judged to be of sufficient potential concern to warrant quantitative risk evaluation:

Exposure Medium	Exposed Receptors	Exposure Route
Soil (surface and subsurface)	Current/future on-site commercial worker Current/future on-site construction worker Future on-site resident	Incidental ingestion
Surface Water	Current/future on-site recreational visitor	Incidental ingestion
Sediment	Current/future on-site recreational visitor	Incidental ingestion

3.3 SELECTION OF CHEMICALS OF POTENTIAL CONCERN

Chemicals of Potential Concern (COPCs) are chemicals which exist in the environment at concentration levels that might be of potential health concern to humans and which are or might be derived, at least in part, from site-related sources.

Soil

The procedure used to identify COPCs for the evaluation of risks to human receptors from soil at this site is shown in Figure 3-3. Chemicals that are not likely to contribute significant risks to humans are eliminated, while chemicals that might be of potential concern are assigned to one of two groups: those that lack the data needed to perform a quantitative evaluation (these are addressed qualitatively), and those that have sufficient data to allow quantitative evaluation. It is important to note that this COPC selection procedure is intended to be conservative; that is, it is expected that some chemicals will be identified as COPCs that are actually of little or no concern, but that no chemicals of authentic concern will be overlooked.

Step 1: Eliminate chemicals for which no toxicity values are available

Risks from chemicals for which USEPA has not established toxicity values (see Section 4) cannot be evaluated quantitatively and so these chemicals were either evaluated semi-quantitatively (essential nutrients) or were assigned to the qualitative COPC category (all other chemicals).

If chemicals without established toxicity values are essential nutrients that are normal constituents of the human body and are required for good health (such as calcium, potassium, sodium), then estimated intake from site media were compared to daily intake values identified by the US Food and Drug Administration. If intake from the site did not substantially exceed the FDA daily values, these minerals were excluded from further consideration. If intake from the site substantially exceeded the FDA daily values, then a semi-quantitative assessment of the relative probability, nature and magnitude of adverse effects was conduced.

Step 2: Eliminate chemicals detected, but whose maximum value is below a level of concern

If a chemical is detected at least once, but the maximum detected concentration is well below a level of health concern, that chemical may be eliminated from further consideration. This screening step was performed using Risk-Based Concentration (RBC) values for soil from the USEPA Regional Screening Tables (USEPA 2009a). Target Risk levels were set to an HQ value of 0.1 and a cancer risk level of 1E-06. Because USEPA Region 3 does not have RBC values for either sediment or surface water, residential soil and tap water RBCs were used, respectively, to screen chemicals in these media.

Step 3: Eliminate chemicals with a detection frequency <5%

In accord with USEPA (1989), a chemical may be eliminated from the quantitative risk assessment if it is detected only infrequently (< 5%) in a site medium. Thus, in this risk assessment chemicals with a detection frequency ≥ 5% were retained and those with a detection frequency < 5% were eliminated from further consideration.

Appendix D presents detailed results of the COPC selection process for soil. Table 3-2 lists the COPCs identified for quantitative evaluation for the human health risk assessment.

Surface Water and Sediment COPCs

Only 5 analytes (arsenic, cadmium, copper, lead and zinc) were measured in surface water and sediment. Instead of conducting a COPC screen for each media analogous to the COPC selection procedure described above, a simplifying assumption was made to retain all of these chemicals for quantitative evaluation in the risk assessment. These COPCs are also presented in Table 3-2.

3.4 QUANTIFICATION OF HUMAN EXPOSURE

3.4.1 Basic Equations

The amount of a chemical which is ingested, inhaled, or taken up across the skin is referred to as "intake" or "dose". For chemicals except lead, which is evaluated differently as discussed in Section 3.4.5, exposure is quantified using an equation of the following general form:

$$DI = C \cdot (IR / BW) \cdot (EF \cdot ED / AT)$$

where:

DI	=	Daily intake of chemical (mg of chemical per kg of body weight per day).
C	=	Concentration of the chemical in the contaminated environmental medium (soil, water) to which the person is exposed. The units are mg/L for water and mg/kg for soil.
IR	=	Intake rate of the contaminated environmental medium. The units are kg/day for soil and L/day for water.
BW	=	Body weight of the exposed person (kg).
EF	=	Exposure frequency (days/year). This describes how often a person is likely to be exposed to the contaminated medium over the course of a typical year.
ED	=	Exposure duration (years). This describes how long a person is likely to be exposed to the contaminated medium during their lifetime.
AT	=	Averaging time (days). This term specifies the length of time over which the average dose is calculated. Usually, two different averaging times are considered:

"Chronic" exposure includes averaging times on the scale of years (typically ranging from 7 years to 70 years). This exposure duration is used when assessing the non-cancer risks from chemicals of concern.

"Lifetime" exposure employs an averaging time of 70 years. This exposure interval is selected when evaluating cancer risks.

Note that the factors EF, ED, and AT combine to yield a factor between zero and one. Values near 1.0 indicate that exposure is nearly continuous over the specified averaging period, while values near zero indicate that exposure occurs only rarely.

For mathematical convenience, the general equation for calculating dose can be written as:

$$DI = C \cdot HIF$$

where:

HIF = Human Intake Factor. This term describes the average amount of an environmental medium contacted by the exposed person each day. The value of HIF is typically given by:

$$HIF = (IR / BW) \cdot (EF \cdot ED / AT)$$

The units of HIF are kg/kg-day for soil and L/kg-day for water.

Because one or more exposure parameters (e.g., intake rates, body weight, exposure frequency) may change as a function of age, exposure calculations are often performed separately for children and adults. In the case of residents, because the same individual may be exposed beginning as a child and extending into adulthood, exposure is calculated as the time-weighted average (TWA) exposure:

$$TWA\ DI = C \cdot [(IRc / BWc) \cdot (EFc \cdot EDc / AT) + [(IRa / BWa) \cdot (EFa \cdot EDa / AT)]$$

where the subscripts "c" and "a" refer to child and adult, respectively.

3.4.2 Selection of Exposure Units

An exposure unit is an area where a receptor (worker or resident) may be exposed to one or more environmental media. Selection of the bounds of an exposure point is based mainly on a consideration of the likely activity patterns of the exposed receptors; that is, an exposure point is an area within which a receptor is likely to spend most of their time and to move about more or less at random.

Soil

For soil, the exposure unit represents an area where a worker or resident might be exposed, based on the anticipated land use for the site (commercial or residential). For commercial use of the site, it is assumed that in the future the site could be utilized as two large commercial areas, the boundaries of which are shown in Figure 3-4. For residential use of the site, future residences are likely to consist of multi-family developments on large parcels of land. Thus, the site was divided up into four residential exposure units, as shown in Figure 3-5. Because a construction worker could be exposed to soil under both commercial and residential land use of the site to work on utilities or constructing structures, the exposure units for a construction worker is assumed to be both the commercial and residential exposure units.

Surface Water and Sediment

Because the concentrations of metals in surface water and sediment may vary between upgradient and downgradient locations in the river, and because each station represents a location where a recreational visitor might be exposed, each sample station was treated as an individual exposure point.

3.4.3 Exposure Point Concentrations

Because of the assumption of random exposure over an exposure area, risk from a chemical in a medium is related to the arithmetic mean concentration of that chemical in that medium, averaged over the entire exposure area. Since the true arithmetic mean concentration cannot be calculated with certainty from a limited number of measurements, the USEPA recommends that the upper 95th percentile confidence limit (UCL) of the arithmetic mean at each exposure point be used when calculating exposure and risk at that location (USEPA 1992a). If the 95% UCL exceeds the highest detected concentration, the highest detected value is used instead (USEPA 1989).

The approach that is most appropriate for computing the 95% UCL of a data set depends on a number of factors, including the number of data points available, the shape of the distribution of the values, and the degree of censoring (USEPA 2002a). At this site, when 5 or more samples were available for a chemical, the EPC was calculated using EPA's ProUCL Software (USEPA 2007). If less than 5 samples were available, the maximum concentration was used as the EPC. Samples that are below the detection limit were evaluated using a value equal to one-half the detection limit. Rejected (R-qualified) data were not used when calculating an EPC.

Appendix E presents tables that summarize the EPCs for each COPC in soil, surface water and sediment. For exposure of residents and commercial workers to soil, only data for surface soil were used when computing EPCs. For exposure of construction workers to soil, both surface and subsurface soil were used, since it is expected that constructions workers would routinely be exposed to both.

3.4.4 Human Exposure Parameters

For every exposure pathway of potential concern, it is expected that there will be differences between different individuals in the level of exposure at a specific location due to differences in intake rates, body weights, exposure frequencies, and exposure durations. Thus, there is normally a wide range of average daily intakes between different members of an exposed population. Because of this, all daily intake calculations must specify what part of the range of doses is being estimated. Typically, attention is focused on intakes that are "average" or are otherwise near the central portion of the range, and on intakes that are near the upper end of the range (e.g., the 95th percentile). These two exposure estimates are referred to as Central Tendency Exposure (CTE) and Reasonable Maximum Exposure (RME), respectively.

The USEPA has collected a wide variety of data and has performed a number of studies to help establish default values for most residential and worker exposure parameters, and some recreational exposure parameters. The chief sources of these standard default values are the following documents:

1. Risk Assessment Guidance for Superfund (RAGS). Volume I. Human Health Evaluation Manual (Part A). USEPA 1989.

2. Human Health Evaluation Manual, Supplemental Guidance: "Standard Default Exposure Factors." USEPA 1991a.

3. Superfund's Standard Default Exposure Factors for the Central Tendency and Reasonable Maximum Exposure. Draft. USEPA 1993.

4. Exposure Factors Handbook. USEPA 1997a.

5. Supplemental Guidance for Developing Soil Screening Levels for Superfund Sites. USEPA 2002a.

Parameters from these guidance documents were used whenever possible. However, USEPA has not established default exposure parameters for some of the exposure pathways of potential concern at this site, so some parameters were selected by use of professional judgment.

The CTE and RME exposure parameters for commercial workers, construction workers, recreational visitors and future residents are listed in Tables 3-3 through 3-6.

3.4.5 Evaluating Human Exposure to Lead

Overview

As noted earlier, risks from lead are evaluated using a somewhat different approach than for most other chemicals. First, because lead is widespread in the environment, exposure can occur by many different pathways. Thus, lead risks are usually based on consideration of total exposure (all pathways) rather than just to site-related exposures. Second, because studies of lead exposures and resultant health effects in humans have traditionally been described in terms of blood lead level, lead exposures and risks are typically assessed using an uptake-biokinetic model rather than calculating an estimated dose. Therefore, calculating the level of exposure and risk from lead in soil also requires assumptions about the level of lead in other media, and also requires use of pharmacokinetic parameters and assumptions that are not needed in traditional methods.

Health-Based Goal for Lead

Excess exposure to lead can result in a wide variety of adverse effects in humans. Chronic low-level exposure is usually of greater concern for young children than older children or adults. There are several reasons for this focus on young children, including the following: 1) young children typically have higher exposures to lead-contaminated media per unit body weight than adults, 2) young children typically have higher lead absorption rates than adults, and 3) young children are more susceptible to effects of lead than are adults.

It is currently difficult to identify what degree of lead exposure, if any, can be considered safe for infants and children. As discussed above, some studies report subtle signs of lead-induced effects in children and perhaps adults beginning at around 10 µg/dL or even lower, with population effects becoming clearer and more definite in the range of 30-40 µg/dL. Of special concern are the claims by some researchers that effects of lead on neurobehavioral performance, heme synthesis, and fetal development may not have a threshold value, and that the effects are long-lasting (USEPA 1986). On the other hand, some researchers and clinicians believe the effects that occur in children at low blood lead levels are so minor that they need not be cause for concern (USEPA 1986).

After a thorough review of all the data, the USEPA identified 10 µg/dL as the concentration level at which effects begin to occur that warrant avoidance, and has set as a goal that there should be no more than a 5% chance that a child will have a blood lead value above 10 µg/dL (USEPA 1991c and 1994a). Likewise, the Centers for Disease Control (CDC) has established a guideline of 10 µg/dL in preschool children which is believed to prevent or minimize lead-associated cognitive deficits (CDC 1991). By analogy, a value of 10 µg/dL is also generally applied to a fetus *in utero*. For convenience, the probability of a blood lead value exceeding 10 µg/dL is referred to as P10.

Lead Exposure Models and Exposure Parameters for Lead

Because the effects of lead exposure are evaluated differently for young children than they are for adults, two separate modeling approaches were used to evaluate risks from exposure to lead at the site: one specific to children (residents) and one appropriate for older individuals (workers and recreational visitors). These approaches are described in further detail below.

Adults

The approach described by Bowers et al. (1994) has been identified by USEPA's Technical Workgroup for Lead (USEPA 1996) as a reasonable interim methodology for assessing risks to adults from exposure to lead and for establishing risk-based concentration goals that will protect older children and adults from lead. For this reason, this method was used for estimating exposure to current or future commercial workers, to lead in soil. When adults are exposed, the sub-population of chief concern is pregnant women and women of child-bearing age, since the blood lead level of a fetus is nearly equal to the blood lead level of the mother (Goyer 1990).

The Bowers model predicts the blood lead level in an adult with a site-related lead exposure by summing the "baseline" blood lead level (PbB0) (that which would occur in the absence of any site-related exposures) with the increment in blood lead that is expected as a result of increased exposure due to contact with a lead-contaminated site medium. The latter is estimated by multiplying the average daily absorbed dose of lead from site-related exposure by a "biokinetic slope factor" (BKSF). Thus, the basic equation for exposure to lead in soil is:

$$PbB = PbB0 + BKSF \cdot [PbS \cdot IRs \cdot AFs \cdot EFs/365]$$

where:

PbB = Geometric mean blood lead concentration (µg/dL) in women of child-bearing age) that are exposed at the site

PbB0 = "Background" geometric mean blood lead concentration (µg/dL) in women of child-bearing age in the absence of exposures to the site

BKSF = Biokinetic slope factor (µg/dL blood lead increase per µg/day lead absorbed)

PbS = Soil lead concentration (µg/g). When exposure occurs over a small area, PbS is usually set equal to the arithmetic mean concentration. When exposure occurs over a larger area, the value of PbS is usually set equal to the 95% UCL of the mean. Because the areas evaluate in this risk assessment are large, the UCL is used in this assessment.

IRs = Intake rate of soil (g/day)

AFs = Absolute gastrointestinal absorption fraction for lead in soil (dimensionless). The value of AFs is given by:

$$AFs = AF(food) \cdot RBA(soil)$$

EFs = Exposure frequency for contact with site soils (days per year)

Once the geometric mean blood lead value is calculated, the full distribution of likely blood lead values in the population of exposed people can then be estimated by assuming the distribution is lognormal with a specified individual geometric standard deviation (GSDi). The 95th percentile of the predicted distribution is given by the following equation (Aitchison and Brown 1957):

$$95th = GM \cdot GSD_i^{1.645}$$

Input values selected for each of these parameters are summarized in Table 3-7. As seen, all of the exposure values for contact with site media are the same as the CTE exposure parameters assumed for other chemicals, and most of the biokinetic parameters are the defaults recommended by USEPA (1996). The baseline blood lead value and the individual geometric mean value are both based on analysis by AGEISS (1996) of blood lead data originally collected by Bornschein in 1994 at the Bingham Creek site, a mining site near Salt Lake City. In this study, blood lead data were obtained for 127 pregnant or nursing women. The baseline blood lead value of 1.7 µg/dL is the geometric mean blood lead concentration for these women, and the GSD_i value of 1.5 was derived from these data using the sliding box model approach recommended by USEPA (1994a).

Children

For lead exposures, the sub-population of chief concern is young children. This is because young children 1) tend to have higher exposures to lead in soil, dust, and paint, 2) tend to have a higher absorption fraction for ingested lead, and 3) are more sensitive to the toxic effects of lead than are older children or adults.

The USEPA has developed an Integrated Exposure Uptake Biokinetic (IEUBK) model for predicting the likely range of blood lead levels in a population of young children (age 0-6 years) exposed to a specified set of environmental lead levels (USEPA 1994b). This model requires as input data on the levels of lead in soil, dust, water, air, and diet at a particular location, and on the amount of these media ingested or inhaled by a child living at that location. All of these inputs to the IEUBK model are central tendency point estimates. These point estimates are used to calculate an estimate of the central tendency (the geometric mean) of the distribution of blood lead values that might occur in a population of children exposed to the specified conditions. Assuming the distribution is lognormal, and given (as input) an estimate of the variability between different children (this is specified by the geometric standard deviation or GSD), the model calculates the expected distribution of blood lead values, and estimates the probability that any random child might have a blood lead value over 10 µg/dL.

For this site, risks to on-site hypothetical future residents from soil were evaluated by running the IEUBK model using the site-specific soil data as input values. The default and site-specific inputs to the IEUBK model are presented in Table 3-8. The GSD recommended as the default for the IEUBK model is 1.6 (USEPA 1994b). However, several blood lead studies that have been performed in the Rocky Mountain West have yielded GSD estimates of about 1.4 (Griffin et al., 1999). Therefore, a GSD value of 1.4 was utilized in this assessment.

Where indoor dust data were not collected, USEPA generally assumes that the concentration of a chemical contaminant in indoor dust is 70-100% of the concentration in outdoor soil. However, studies that have been performed at a number of mining/smelting sites in the Rocky Mountain West have indicated that this assumption is often somewhat over-conservative (USEPA 2001a and 2002c; Weston 1995 and 1997). These data are summarized in the table below.

Site	Location	Soil-Dust Relationship for Lead
Bingham Creek	Utah	0.43
California Gulch	Colorado	0.25
Eureka Mills	Utah	0.15
Murray Smelter	Utah	0.19
Vasquez Boulevard and Interstate 70	Colorado	0.34

As seen, most estimates of indoor dust are approximately 20%-30% of outdoor soil (slope values of 0.2 – 0.3) or less. In order to be conservative, the highest soil-dust relationship (Bingham Creek) was used to estimate indoor dust concentrations at the VBI70 OU2 site.

Baseline risks to children from lead were calculated using the exposure values presented in Table 3-8. The concentration of lead in baseline soil was assumed to be 165 mg/kg, since this is the value that yields a geometric mean blood lead level of 2.7 µg/dL, which is the reported geometric mean blood lead level for U.S. children ages 1-5 (Pirkle et al. 1998).

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4.0 TOXICITY ASSESSMENT

The basic objective of a toxicity assessment is to identify what adverse health effects a chemical causes, and how the appearance of these adverse effects depends on exposure level. In addition, the toxic effects of a chemical frequently depend on the route of exposure (oral, inhalation, dermal) and the duration of exposure (subchronic, chronic, or lifetime). Thus, a full description of the toxic effects of a chemical includes a listing of what adverse health effects the chemical may cause, and how the occurrence of these effects depends upon dose, route, and duration of exposure.

4.1 TOXICITY FACTORS FOR HUMAN HEALTH

4.1.1 Basic Methods

The toxicity assessment process is usually divided into two parts: the first characterizes and quantifies the non-cancer effects of the chemical, while the second addresses the cancer effects of the chemical. This two-part approach is employed because there are typically major differences in the time-course of action and the shape of the dose-response curve for cancer and non-cancer effects.

Non-Cancer Effects

Essentially all chemicals can cause adverse health effects if given at a high enough dose. However, when the dose is sufficiently low, typically no adverse effect is observed. Thus, in characterizing the non-cancer effects of a chemical, the key parameter is the threshold dose at which an adverse effect first becomes evident. Doses below the threshold are considered to be safe, while doses above the threshold are likely to cause an effect.

The threshold dose is typically estimated from toxicological data (derived from studies of humans and/or animals) by finding the highest dose that does not produce an observable adverse effect, and the lowest dose which does produce an effect. These are referred to as the "No-observed-adverse-effect-level" (NOAEL) and the "Lowest-observed-adverse-effect-level" (LOAEL), respectively. The threshold is presumed to lie in the interval between the NOAEL and the LOAEL. However, in order to be conservative (protective), non-cancer risk evaluations are not based directly on the threshold exposure level, but on a value referred to as the Reference Dose (RfD). The RfD is an estimate (with uncertainty spanning perhaps an order of magnitude) of a daily exposure to the human population (including sensitive subgroups) that is likely to be without an appreciable risk of deleterious effects during a lifetime.

The RfD is derived from the NOAEL (or the LOAEL if a reliable NOAEL is not available) by dividing by an "uncertainty factor". If the data are from studies in humans, and if the observations are considered to be very reliable, the uncertainty factor may be as small as 1.0. However, the uncertainty factor is normally at least 10, and can be much higher if the data are limited. The effect of dividing the NOAEL or the LOAEL by an uncertainty factor is to ensure that the RfD is not higher than the threshold level for adverse effects. Thus, there is always a "margin of safety" built into an RfD, and doses equal to or less than the RfD are nearly certain to be without any risk of adverse effect. Doses higher than the RfD may carry some risk, but because of the margin of safety, a dose above the RfD does not mean that an effect will necessarily occur.

Cancer Effects

For cancer effects, the toxicity assessment process has two components. The first is a qualitative evaluation of the weight of evidence (WOE) that the chemical does or does not cause cancer in humans. Typically, this evaluation is performed by the USEPA, using the system summarized below:

WOE Group	Meaning	Description
A	Known human carcinogen	Sufficient evidence of cancer in humans.
B1	Probable human carcinogen	Suggestive evidence of cancer incidence in humans.
B2	Probable human carcinogen	Sufficient evidence of cancer in animals, but lack of data or insufficient data in humans.
C	Possible human carcinogen	Suggestive evidence of carcinogenicity in animals.
D	Cannot be evaluated	No evidence or inadequate evidence of cancer in animals or humans.

For chemicals which are classified in Group A, B1, B2, or C, the second part of the toxicity assessment is to describe the carcinogenic potency of the chemical. This is done by quantifying how the number of cancers observed in exposed animals or humans increases as the dose increases. Typically, it is assumed that the dose response curve for cancer has no threshold, arising from the origin and increasing linearly until high doses are reached. Thus, the most convenient descriptor of cancer potency is the slope of the dose-response curve at low doses (where the slope is still linear). This is referred to as the Slope Factor (SF), which has dimensions of risk of cancer per unit dose.

Estimating the cancer Slope Factor is often complicated by the fact that observable increases in cancer incidence usually occur only at relatively high doses, frequently in the part of the dose-response curve that is no longer linear. Thus, it is necessary to use mathematical models to extrapolate from the observed high dose data to the desired (but unmeasurable) slope at low dose. In order to account for the uncertainty in this extrapolation process, USEPA typically chooses to employ the upper 95th confidence limit of the slope as the Slope Factor. That is, there is a 95 percent probability that the true cancer potency is lower than the value chosen for the Slope Factor. This approach ensures that there is a margin of safety in cancer as well as non-cancer risk estimates.

4.1.2 Human Toxicity Values

Toxicity values (RfD and SF values) are often estimated by a variety of different groups or agencies. USEPA (2003c) describes the recommended hierarchy for selecting toxicity values for use in human health risk assessment at Superfund sites. The first preference is for USEPA consensus values as listed in the Integrated Risk Information System (IRIS), an electronic database containing human health assessments for various chemicals (available online at http://www.epa.gov/iris/). If values are not available from IRIS, the next preference is to seek Provisional Peer Reviewed Toxicity Values for Superfund (PPRTVs) developed by EPA's Superfund Health Risk Technical Support Center (STSC). If PPRTVs are not available, toxicity values may be obtained from other sources, such as the Agency for Toxic Substances and Disease Registry (ATSDR) Minimal Risk Levels (MRLs) (available online at http://www.atsdr.cdc.gov/mrls.html), California EPA's Toxicity Criteria Database (available online at http://www.oehha.ca.gov/risk/ChemicalDB/index.asp), and USEPA's Health Effects Assessment Summary Tables (HEAST) (USEPA 1997c). Most of these values are also compiled in the USEPA Regional Screening Tables (USEPA 2009a).

Table 4-1 summarizes the toxicity values used for evaluation of human health risks from quantitative COPCs at this site. Values were selected in accordance with USEPA (2003d). Points to note regarding the data in this table are listed below:

- Two oral RfD values are available for cadmium, depending on exposure medium (water, food). The value for food is assumed to apply to soil.

- The RfD for manganese in soil and water (0.023 mg/kg-day) is based on the oral RfD of 1.4E-01 mg/kg-day in the diet. In accord with recommendations in IRIS, this value is modified by dividing by a Modifying Factor of 3 for application to exposures from soil or water.

4.2 ADJUSTMENTS FOR RELATIVE BIOAVAILABILITY

Accurate assessment of human exposure to chemicals in the environment requires knowledge of the amount of metal absorbed into the organism following contact with a contaminated medium. This information is especially important for environmental media such as soil or mine wastes, because metals in these media may exist, at least in part, in a variety of poorly water soluble minerals, and may also exist inside particles of inert matrix such as rock or slag. These chemical and physical properties may tend to influence (usually decrease) the absorption (bioavailability) of the metals.

If data are available on the availability of a chemical in a site medium (e.g., soil) compared to the bioavailability of that chemical in whatever medium was used to develop a human toxicity value, the ratio of the bioavailability values can be used to adjust the toxicity values to yield an improved estimate of risk at the site.

The ratio of the absorption fraction for a chemical in site medium compared to the medium used in the key toxicity studies is referred to as the Relative Bioavailability (RBA). If reliable estimates of RBA are available for chemicals of potential concern in site media, these can be used to adjust the default RfD and SF values as follows:

$$RfD_{adj} = RfD_{default} / RBA$$
$$SF_{adj} = SF_{default} \cdot RBA$$

4.2.1 Site-Specific Estimates of RBA for Lead and Arsenic in Soil

In general, the most reliable means for obtaining absorption data on a metal that is present in a particular soil or mine waste is to study the rate and extent of absorption of the metal when the material is fed to an appropriate test animal. *In vivo* studies exist for the absorption of arsenic and lead in soils from this site.

Arsenic RBA

For arsenic, USEPA performed a study in which five separate samples were fed to swine for 12 days. Swine were selected as the test species because it is believed the gastrointestinal system (and hence the behavior of ingested arsenic) in swine is similar to that in humans. The details of the study design and of the findings are presented in a separate report (USEPA 2001b). In brief, the study found that arsenic in site soils was less well absorbed than a readily soluble form of arsenic (sodium arsenate), with RBA values for individual samples of site soil ranging from about 0.18 to 0.45. Because it is believed that these differences in RBA reflect mainly experimental variation, a single site-wide RBA value was derived by calculating the 95% upper confidence limit of the mean RBA for all of the site soils tested. The resulting value was 0.42. This arsenic soil RBA was used to evaluate risks to workers and residents in this assessment.

Lead RBA

For lead, In order to investigate the relative bioavailability of lead in site soils, USEPA Region VIII performed a study in which two separate samples of site soil were fed to swine for 15 days. Swine were selected as the test species because it is believed the gastrointestinal system (and hence the behavior of ingested lead) in swine is similar to that in humans. The details of the study design and of the findings are presented in a separate report (USEPA 2001c). In brief, the study found that lead in site soils was absorbed by swine about 81-87% (mean = 84%) as well as a readily soluble form of lead (lead acetate). This *in vivo* estimate is supported by the bioaccessability measured in vitro:

In Vivo Bioavailability and In Vitro Bioaccessability Measurements of VBI70 Site Soils

Test Material	Sample Location	In Vivo Relative Bioavailability (%)	In Vitro Bioaccessability (%)
Sample 1	Eastern part of site	87%	86%
Sample 2	Western part of site	81%	85%*

* Mean of duplicate analyses

Based on these site-specific data, an RBA of 84% was used in the evaluation of lead risks. Note that this RBA value is somewhat higher than the typical USEPA default value of 60%, suggesting that the lead in site soils is in a form that can be readily absorbed. Based on a default absorption fraction of 50% for lead in water and food, an RBA of 84% corresponds to an absolute bioavailability (ABA) of 42% (0.42).

4.2.2 Site-Specific Estimates of RBA for Other Chemicals in all Media

No site-specific data were available on the relative bioavailability of the other COPCs in soil or for COPCs in any other environmental media. In the absence of site-specific data, the RBA for all chemicals in all media was assumed to be 1.0 (USEPA 1989).

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5.0 HUMAN HEALTH RISK CHARACTERIZATION

5.1 BASIC METHODS

5.1.1 Non-Cancer

Non-Lead COPCs

For most chemicals (except lead), the potential for non-cancer effects is evaluated by comparing the estimated daily intake of the chemical over a specific time period with the RfD for that chemical derived for a similar exposed period. This comparison results in a non-cancer Hazard Quotient (HQ), as follows (USEPA 1989):

$$HQ = DI / RfD$$

where:

HQ	=	Hazard Quotient
DI	=	Daily Intake (mg/kg-day)
RfD	=	Reference Dose (mg/kg-day)

If the HQ for a chemical is equal to or less than one (1E+00), it is believed that there is no appreciable risk that non-cancer health effects will occur. If an HQ exceeds 1E+00, there is some possibility that non-cancer effects may occur, although an HQ above 1E+00 does not indicate an effect will definitely occur. This is because of the margin of safety inherent in the derivation of all RfD values (see Section 4). However, the larger the HQ value, the more likely it is that an adverse effect may occur.

If an individual is exposed to more than one chemical, a screening-level estimate of the total non-cancer risk is derived simply by summing the HQ values for that individual. This total is referred to as the Hazard Index (HI). If the HI value is less than 1E+00, non-cancer risks are not expected from any chemical, alone or in combination with others. If the screening level HI exceeds 1E+00, it may be appropriate to perform a follow-on evaluation in which HQ values are added only if they affect the same target tissue or organ system (e.g., the liver). This is because chemicals which do not cause toxicity in the same tissues are not likely to cause additive effects.

Lead

As described in Section 3.5, non-cancer risks from exposure to lead are evaluated using a somewhat different approach. In brief, mathematical models are used to estimate the distribution of blood lead values in a population of people exposed to lead under a specified set of conditions.

Health risks are judged to be acceptable if there is no more than a 5% chance that an exposed individual (a child or a woman of child-bearing age) will have a blood lead level that exceeds 10 μg/dL. For convenience, this probability is referred to as P10.

5.1.2 Cancer

The excess risk of cancer from exposure to a chemical is described in terms of the probability that an exposed individual will develop cancer because of that exposure by age 70. For each chemical of concern, this value is calculated from the daily intake of the chemical from the site, averaged over a lifetime (DIL), and the slope factor (SF) for the chemical, as follows (USEPA 1989):

$$\text{Excess Cancer Risk} = 1 - \exp(-\text{DIL} \cdot \text{SF})$$

In most cases (except when the product of DIL · SF is larger than about 0.01), this equation may be accurately approximated by the following:

$$\text{Excess Cancer Risk} = \text{DIL} \cdot \text{SF}$$

Excess cancer risks are summed across all chemicals of concern and all exposure pathways that contribute to exposure of an individual in a given population.

The level of total cancer risk that is of concern is a matter of personal, community, and regulatory judgment. In general, the USEPA considers excess cancer risks that are below about 1E-06 to be so small as to be negligible, and risks above 1E-04 to be sufficiently large that some sort of remediation is desirable. Excess cancer risks that range between 1E-04 and 1E-06 are generally considered to be acceptable (USEPA 1991b), although this is evaluated on a case by case basis, and USEPA may determine that risks lower than 1E-04 are not sufficiently protective and warrant remedial action.

5.2 RESULTS

5.2.1 Risks from Ingestion of Soil

The detailed calculations of non-cancer and cancer risks for commercial workers, construction workers and hypothetical future residents from the incidental ingestion of soil are presented in Appendix F and the results are summarized, by receptor, below. In accord with USEPA guidance, all risk values are expressed to one significant figure.

Commercial Worker

Table 5-1 summarizes the risks to a commercial worker from the ingestion of surface soil. As seen, estimated CTE and RME cancer risks for a current or future commercial worker are below or within USEPA's risk range of 1E-06 to 1E-04 at both exposure units. Additionally, estimated CTE and RME noncancer risks are also below a level of potential concern (HI<1E+00) in surface soil at both exposure units.

Table 5-1 also shows the probability of a current or future a pregnant commercial worker having an exposure that would result in a blood lead value that could be of concern to a fetus (PbB > 10 µg/dL), or P10. As seen, the concentration of lead in surface soil at commercial unit C1 is below a level of concern, but exposure to lead is of potential concern (P10 = 70%) in commercial unit C2.

Construction Worker

Table 5-2 summarizes the current and future risks to a construction worker from the ingestion of surface soil at residential exposure units (Panel A) and commercial exposure units (Panel B). As seen, estimated CTE and RME cancer risks for a current or future construction worker are below or within USEPA's risk range (target cancer risk of 1E-06 - 1E-04, and noncancer risks are also below a level of concern HI<1E+00) at all residential and commercial exposure units. This indicates that exposure to non-lead COPCs is not of concern to construction workers at the site.

Table 5-2 also shows the probability of a current or future a pregnant construction worker having an exposure that would result in a blood lead value that could be of concern to a fetus (PbB > 10 µg/dL), or P10. As seen, exposures are below a level of concern at Exposure Units R1, R3, R4, and C1, but are above a level of concern at Exposure Units R2 (P10 > 95%) and C2 (P10 = 18%).

Hypothetical Future Residents

Table 5-3 summarizes risks to hypothetical future residents from the ingestion of surface soil.

Estimated CTE and RME cancer risks are within USEPA's risk range for cancer (1E-06 to 1E-04) at all exposure units. For noncancer, estimated CTE risks are below a level of concern for CTE receptors, but exceed a level of concern for an RME resident of exposure unit R2 due primarily to the concentrations of arsenic, manganese and thallium in surface soil.

Table 5-3 also presents the probability of a future residential child having an exposure that would result in a blood lead value above 10 µg/dL. As seen, the concentration of lead in surface soil is below a level of concern (P10 < 5%) for a child resident in Exposure Unit R4, but is slightly above a level of concern for Exposure Units R1 (P10 = 6.9%) and R3 (P10 = 5.9%), and very high for Exposure Unit R2 (P10 > 95%).

5.2.2 Risks from Ingestion of Surface Water and Sediment

Recreational Visitors

Table 5-4 summarizes the cancer and noncancer risks to a recreational visitor from the incidental ingestion of surface water (Panel A) and sediment (Panel B) along the South Platte River. As seen, cancer risks are below USEPA's risk range of 1E-06 to 1E-04, and noncancer risks are below a level of concern (HI <1E+00) at all locations.

Table 5-4 also shows the probability of a pregnant recreational visitor having an exposure that would result in a blood lead value that could be of concern to a fetus (PbB > 10 µg/dL). As seen, lead concentrations in surface water and sediment would not result in a recreational visitor having an exposure that would result in a blood lead level that exceeds USEPA's health based goal for a fetus ($P10_{fetus} < 5\%$).

Table 5-5 presents the combined risks to recreational children/adolescents playing in the South Platte River from the incidental ingestion of surface water and sediment. Total non-cancer and cancer risks are below a level of concern at all locations. Risks from lead are also below a level of concern at all locations.

These results indicate that there is little risk to recreational visitors who may have contact with surface water or sediment along the South Platte River.

6.0 UNCERTAINTIES

Quantitative evaluation of the risks to humans from environmental contamination is frequently limited by uncertainty regarding a number of key data items, including concentration levels in the environment, the true level of human contact with contaminated media, and the true dose response curves for non cancer and cancer effects in humans. This uncertainty is usually addressed by making assumptions or estimates for uncertain parameters based on whatever limited data are available. Because of these assumptions and estimates, the results of risk calculations are themselves uncertain, and it is important for risk managers and the public to keep this in mind when interpreting the results of a risk assessment. The following sections review the main sources of uncertainty in the risk calculations performed at the VBI70 OU2 site.

6.1 Uncertainties in Exposure Assessment

As described above, the risk assessment process begins with estimation of human exposure to potentially toxic chemicals in environmental media. There are multiple sources of uncertainty in these exposure estimates, as discussed below.

Uncertainties from Exposure Pathways Not Evaluated

As discussed in Section 3 (see Figure 3-1), humans may be exposed to site related chemicals by a number of pathways, but not all of these pathways were evaluated quantitatively in this risk assessment. For example, at this site, the following pathways were omitted: dermal exposure to all media (soil, sediment, and surface water), inhalation of dust in air, and ingestion of aquatic food items. These pathways were omitted because it is believed these pathways contribute only a small amount of risk compared to one or more other pathways that were evaluated. In these cases, omission of the minor pathways will result in a small underestimation of exposure and risk, but the magnitude of this underestimation is not expected to be significant. In the case of dermal exposure to soil or water, the magnitude of the underestimation is generally presumed to be small, but this may vary between different chemicals and different exposure pathways, and might become significant in some cases (e.g., dermal contact for a construction worker). If so, that would result in an underestimation of risk to that population.

Uncertainties From Chemicals Not Evaluated

As discussed in Section 3.3, exposure and risk were quantified only for a selected subset (the COPCs) of chemicals detected in environmental media. In most cases, omission of other (non-COPC) chemicals is not a significant source of uncertainty, since the highest level of the chemical detected did not exceed a level of concern. However, some chemicals were not evaluated because no toxicity factor was available. This omission may tend to underestimate total risk, but the magnitude of the error is likely to be low This is because absence of a toxicity value is generally the result of a low level of concern over the chemical. Thus, chemicals that lack toxicity factors may contribute some added risk to exposed humans, but the level of added risk is not expected to be large.

Uncertainties in Exposure Point Concentrations

In all exposure calculations, the desired input parameter is the true mean concentration of a contaminant within a medium, averaged over the area where random exposure occurs. However, because the true mean cannot be calculated based on a limited set of measurements, the USEPA (1989, 1992) recommends that the exposure estimate be based on the 95% upper confidence limit (UCL) of the mean. When data are plentiful and inter sample variability is not large, the EPC may be only slightly higher than the mean of the data. However, when data are sparse or are highly variable, the EPC may be far greater than the mean of the available data. Such EPCs (substantially higher than the sample mean) reflect the substantial uncertainty that exists when data are sparse or highly variable, and in general are likely to result in an overestimate of risk.

At this site, the EPC was the 95% UCL or the maximum concentration. The 95% UCL was calculated when 4 or more sample results were available for a chemical. In cases where less than 4 sample results were available, the maximum concentration was used as the EPC. The data sets for surface water, sediment, groundwater and soil were somewhat limited, and the maximum concentration was often used as the EPC at the majority of these exposure units. In cases where the inter sample variability is small, this is not likely to overestimate the mean concentration and risk estimates. However, in cases where the data are highly variable the maximum could result in an overestimate of risk. Overall, uncertainties in exposure point concentrations are more likely to overestimate than underestimate risks.

Uncertainties in Human Exposure Parameters

Accurate calculation of risk values requires accurate estimates of the level of human exposure that is occurring. However, many of the required exposure parameters are not known with certainty and must be estimated from limited data or knowledge. For example, data on the actual frequency and duration of exposures of current site visitors and future construction workers are not known. Likewise, data are absent on the amount of exposure to site media (soil, water, sediment) by current or future on-site workers and visitors, and values were derived based mainly on professional judgment. In general, the exposure parameters were chosen in a way that was intended to be conservative. Therefore, the values selected are thought to be more likely to overestimate than underestimate actual exposure and risk.

Uncertainties in Chemical Absorption (RBA)

The risk from an ingested chemical depends on how much of the ingested chemical is absorbed from the gastrointestinal tract into the body. This issue is especially important for metals in soil at mining sites, because some of the metals may exist in poorly absorbable forms, and failure to account for this may result in a substantial overestimation of exposure and risk. In the absence of site-specific data, the default approach (followed in this document) is to assume that the RBA is 100% for most chemicals, with the exception of the site-specific RBA of 42% for arsenic and 84% for lead in soil. Use of these default assumptions is more likely to overestimate than underestimate true exposures.

6.2 Uncertainties in Toxicity Values

Human Health Toxicity Values

Toxicity information for many chemicals is often limited. Consequently, there are varying degrees of uncertainty associated with toxicity values (i.e., cancer slope factors, reference doses). For example, uncertainties can arise from extrapolation from animal studies to humans, extrapolation from high dose to low dose, and extrapolation from continuous exposure to intermittent exposure. In addition, in some cases, only a few studies are available to characterize the toxicity of a chemical, and uncertainties exist not only in the dose response curve, but also in the nature and severity of the adverse effects which the chemical may cause. USEPA typically deals with this uncertainty by applying an uncertainty factor of 10 - 100 to account for limitations in the database. Thus, in cases where available data do identify the most sensitive endpoint of toxicity, risk estimates will substantially overestimate true hazard.

In general, uncertainty in toxicity factors is one of the largest sources of uncertainty in risk estimates at a site. Because of the conservative methods USEPA uses in dealing with the uncertainties, it is much more likely that the uncertainty will result in an overestimation rather than an underestimation of risk.

6.3 Uncertainties in Risk Estimates

A number of limitations are associated with the risk characterization approach for carcinogens and non-carcinogens.

First, because risk estimates for a chemical are derived by combining uncertain estimates of exposure and toxicity (see above), the risk estimates for each chemical are more uncertain than either the exposure estimate or the toxicity estimate alone. However, even if the risk estimates for individual chemicals were quite certain, there is considerable uncertainty in how to combine risk estimates across different chemicals. In some cases, the effects caused by one chemical do not influence the effects caused by other chemicals. In other cases, the effects of one chemical may interact with effects of other chemicals, causing responses that are approximately additive, greater than additive (synergistic), or less than additive (antagonistic). In most cases, available toxicity data are not sufficient to define what type of interaction is expected, so EPA generally assumes effects are additive for non carcinogens that act on the same target tissue and for carcinogens (all target tissues). Because documented cases of synergistic interactions between chemicals are relatively uncommon, this approach is likely to be conservative for most chemicals.

For non carcinogens, summing HQ values across different chemicals is properly applied only to compounds that induce the same effect by the same mechanism of action. Consequently, summation of HQ values for compounds that are not expected to include the same type of effects or that do not act by the same mechanisms could overestimate the potential for effects. Thus, all of the HI values in this report, which sum HQ values across multiple metals, are likely to overestimate the true level of human health non-cancer hazard.

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